have been due partly to its location in an opening of less than 125 feet radius, and partly to the location of the corresponding forested station less than 100 feet within a stand of thin crowned lodgepole pine. Under the latter conditions but slight protection is received from either direct sunshine or currents of warm air. A similar statement holds good for station *4 forest* of the Yakima area, as shown in Tables 2 and 3.

Because of defects in the sampling tube used, measurements of density on the Tumalo area were too irregular for complete confidence. The limits of the average densities used are from 36 per cent in the early measurements to 45 per cent for the last measurements.

Drifting by the wind was of comparatively small importance throughout the study. Very large and deep snow drifts occur on comparatively small areas near the summit of the Cascade Range, but are not found on the middle slopes or on these areas. The lesser blowing and drifting of snow, chiefly in the open areas, appears to be practically self-compensating.

The results of this study are in general accordance with Swiss figures quoted by Fernow[1]—that the retardation of snow melting in forests is 5 to 8 days in general and may be several weeks—and also with the above mentioned observations by Church. In agreement with the latter is the tendency of the snow in the forest to be deepest and last longest in the small openings of the denser forests. This tendency was especially noted on the Wind River area and may partly account for the late melting of the snow in the small open areas characteristic of the Tumalo area. In large openings the protecting influence from the forest would be dissipated and melting consequently more rapid.

An unusual factor in delaying the melting within the Douglas fir type of forest is the protection given by the irregular layer of even very slight bits of moss, twigs, bark, and other litter weathered from the trees. Fragments like those shown in figure 2, which in the open would materially hasten melting by absorbing solar heat, in the forest serve as a crude but effective insulation from the warmer air currents above the snow. In a more open forest this effect is less prominent.

An opposing influence appears in the ability of bushes, tree trunks, and other large objects to hasten melting by radiating or reflecting into the snow the heat which they receive from various sources. Hollows or bare spots around trees, etc., are frequently noted in the spring. They seem to be important in all coniferous forests but especially in those of the yellow pine type.

Application of results.

Expressed in irrigation terms, the figures given in Table 1 mean that on the areas studied the average square mile of forest cover retained the equivalent of between 720 and 160, averaging 400, acre-feet of water in the form of snow after the open areas had become bare. Neglecting losses through seepage and evaporation, the average of 400 acre-feet is sufficient supply for about 150 acres of cultivated land for the entire season, or for about 650 acres for one month during the peak of the irrigation season (during the summer low-water period). Of course some loss is to be expected in the natural flow of the water down to the lower valley; but it will, at a time when the ground is already saturated, be much less than the normal loss. It is also probable that some of the water will flow down stream too early to be of greatest use in irrigation. Making considerable allowance for these losses, it appears that the forest cover is a very important and very valuable factor in increasing water available for irrigation.

In terms of time, the effect of the forests was to spread the 400 acre-feet of retained snow water through a period averaging 17 days in length. The retardation of this amount of snow is sufficient to be of great importance to irrigation interests, especially as it is generally understood that a forest cover tends to "flatten out" the crest of a flood, and thus to increase the minimum flow at periods of low water. A forest cover thus supplements the possible artificial reservoirs. This study furnishes measurements, however, not of stream flow but only of the material out of which stream flow is made.

Summary.

The study of snow melting in the open and in the forests of three areas on the Columbia River watershed showed that the snow remains an average of 17 days longer in the forest.

Drifting occurred only on the higher ridges of these areas and chiefly in the open, though the late snowbanks in the forest had very much the appearance of drifts. Because of the retention of snow on the crowns of trees and the resulting increased evaporation, the snow cover usually reached a depth greater in the open than in the forest.

The depth of snow retained was considerably greater in a dense forest than in an open forest, at least during the latter part of the melting season. For the areas studied, the snow remaining in the forested stations, at the time the open stations became bare, was equal to 7.5 surface inches of water or about 30 per cent of the maximum snow blanket. With the forest areas at higher altitudes and with stations located so as to prevent completely the influence of open areas on the forested stations, and vice versa, the effect was found to be noticeably greater than this.

[1] Fernow, B. E., Forest Influences, Bull. 7, Div. of Forestry, p. 137.

SNOWFALL ON MOUNT RAINIER, WASH.

By LAWRENCE C. FISHER.

[Dated: Weather Bureau Office, Seattle, Wash., May 24, 1918.]

Mount Rainier, standing to the west of the main range of the Cascades, rises to a height of 14,408 feet in nearly unobstructed view from the shores of Puget Sound. The low peaks about its base, which were originally a part of the mountain before glaciers cut its flanks, appear to merge into the contour of the mountain when viewed from the Sound, and the mountain itself towers high above the main range of the Cascades 12 miles to the east. The upper and more conspicuous half is clothed with an eternal mantle of snow, while a score of glaciers extend for several miles farther down the deep valleys. En route to the sea, a fraction of the power of its never-failing streams has been captured and transformed to illuminate towns and cities and turn the wheels of industry. One marvels at the rushing torrents of water, and wonders what may be the quantity of snow and rain this great and unshielded mountain takes from the passing winds each year. It is a subject worthy of extended observations and study.

A daily record of snowfall was made during most of the season 1916–17 at Paradise Inn on the south slope of Mount Rainier at an elevation of 5,500 feet. Although

observations were not begun until November 24, 1916, the total measured snowfall from that time to the last snowstorm before midsummer in 1917 is apparently greater than for any other station in the United States for any entire season, with the single exception of Tamarack, Cal., in 1906–07. Below is the snowfall record for Paradise Inn by months in inches:

Snowfall at Paradise Inn, Mount Rainier.

1916			1917							Total.
On ground Nov. 24.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	
36	[1] 61	123	131	77	206	94	14	47.5	0	789.5

[1] 7 days.

Some of the more notable snowfall records made prior to this are the following:[2] At the Musick station in Oregon, elevation 5,000 feet, the total snowfall for the season 1912–13 was 612.7 inches; at Government Camp, Oreg., elevation 3,890 feet, 590 inches were recorded in 1898–99; the greatest snowfall at Summit, Cal., in 44 winters, elevation 7,017 feet, is 783 inches in 1879–80; at Tamarack, Cal., elevation 8,000 feet, the greatest snowfall in eight winters is 884 inches in 1906–07;[3] on the summit of Pikes Peak, Colo., elevation 14,134 feet, 743.3 inches of snow fell in the season of 1892–93.

The Paradise Inn record is the first obtained west of the summit of the Cascades in Washington at so great an elevation. The more elevated mountain snowfall stations have been limited to points along railway lines, to mining camps, and to mountain inns which usually are primarily summer resorts. In this State the passes permit railways to cross the mountains at comparatively low elevations. The highest mining camps from which records have been obtained lie on the eastern or leeward slopes of the Cascades, where, though the snowfall is very heavy, it is less than on the western slopes. The construction of a large and substantial hotel building in Paradise Valley in the summer of 1916 made possible this interesting observing station. Mr. E. H. Frank, custodian of the inn for the winter, proved a careful and faithful observer. He erected a graduated snow stake at a point approximately 200 feet to the northwest of the westerly wing of the building, where conditions appeared to be most favorable for obtaining average snowfall measurements. Both the amount of freshly fallen snow and the accumulated depth were measured daily throughout the period. Owing to the lateness of the season when the station was established, no rain-and-snow gage was provided, but the usual self-registering maximum and minimum thermometers were supplied by the Weather Bureau and were exposed on the northeast end of the hotel. The observer improvised a shelter to screen the thermometers from the direct rays of the sun. As the depth of the snow increased the instruments were attached higher and higher on the wall of the hotel. Egress and ingress to the hotel was by means of tunnels through the snow to windows of the wing designed for the accommodation of guests. These tunnels required frequent reconstruction.

[2] See also Palmer, Andrew H., The region of greatest snowfall in the United States. This Review, May, 1915, 43:217–221.—Editor.

[3] In a letter dated Aug. 27, 1918, Mr. Palmer states that in his paper above quoted this record was overlooked in the selection of extreme maximum snowfall, although included in determining the average seasonal snowfall.—Editor.

Apparently a complete record was not made of the number of times rain fell at the station, but temperatures indicate the possibility of rain in each month. In February notation of rain was made on three dates, and again in April rain was noted three times. It is quite probable that rain fell in other months to some extent.

The national park ranger, Mr. J. B. Flett, has the full equipment for cooperative observers at Longmires Springs, the elevation of which is 2,761 feet, and has kept a meteorological record for a number of years. In addition, for several seasons he has made measurements of snowfall depths on the 15th and last day of each month near the foot of Nisqually Glacier, elevation 3,908 feet, and near Narada Falls, elevation 4,572 feet. Readings for these two dates in each month during the season of 1916–17 for the four different points of observation on the south slope of Mount Rainier are shown graphically in Figure 1.

As the daily readings are available for the Longmires and Paradise stations, their graphs have been drawn to include the maximum depth at the time observed. Readings at the foot of Nisqually Glacier and Narada Falls began with January 31 and ended with June 30. No data are available for May 31. It will be noted that fluctuations in graphs for the regular cooperative stations at Longmires Springs and Paradise Inn, the lowest and the highest stations, respectively, harmonize most closely.

Although daily snowfall measurements have never been made previously at Paradise Inn, there are grounds for the belief that the season 1916–17 was not one of maximum snowfall. To be sure, the snow remained on the ground longer than usual, even as late as or a few days later than the preceding season, when snowfall was unusually great; but its long continuance was probably due to the low temperatures that prevailed most of the season, and to the heavy snowfall in March. Records for other mountain snowfall stations show considerably more snow in the season 1915–16 than in 1916–17. At Longmires Springs the total snowfall from November to May, inclusive, in the season 1915–16 was 327 inches, as compared with 296 inches for the same period in 1916–17; and the water content of all kinds of precipitation was 78.01 inches for the former season as compared with 58.88 inches for the latter. From February to May, inclusive, the temperature averaged 3° lower in 1917 than in 1916, and this accounts for the smaller snowfall of 1916–17 remaining on the ground a little longer than the heavier fall of the season before. At Goat Lake, elevation 2,900 feet, in the season of 1915–16, 622 inches fell, while in 1916–17 the amount was 443.5 inches, which is less than the seven-year average. At Tye, elevation 3,115 feet, the earlier season had 520.5 inches and 1916–17 had 471 inches. At Cascade Tunnel, elevation 3,373 feet, the 1915–16 season had 717 inches and 1916–17, 594 inches. Therefore it seems probable that the snowfall at Paradise Inn for the season 1915–16 exceeded that for 1916–17, and that this total of 789.5 inches can not be considered to have occurred in a season of maximum snowfall.

Again, the question arises whether Paradise Inn is located on the slope that would receive the greatest precipitation. Normally the heaviest precipitation in Washington is found on the windward side of mountains. The prevailing direction of surface winds is generally southwest or west, and the clouds move from this quarter even more frequently than the surface winds. During the winter of 1916–17 the daily eye observations of the wind at the Inn gave an average direction somewhat south of west. It

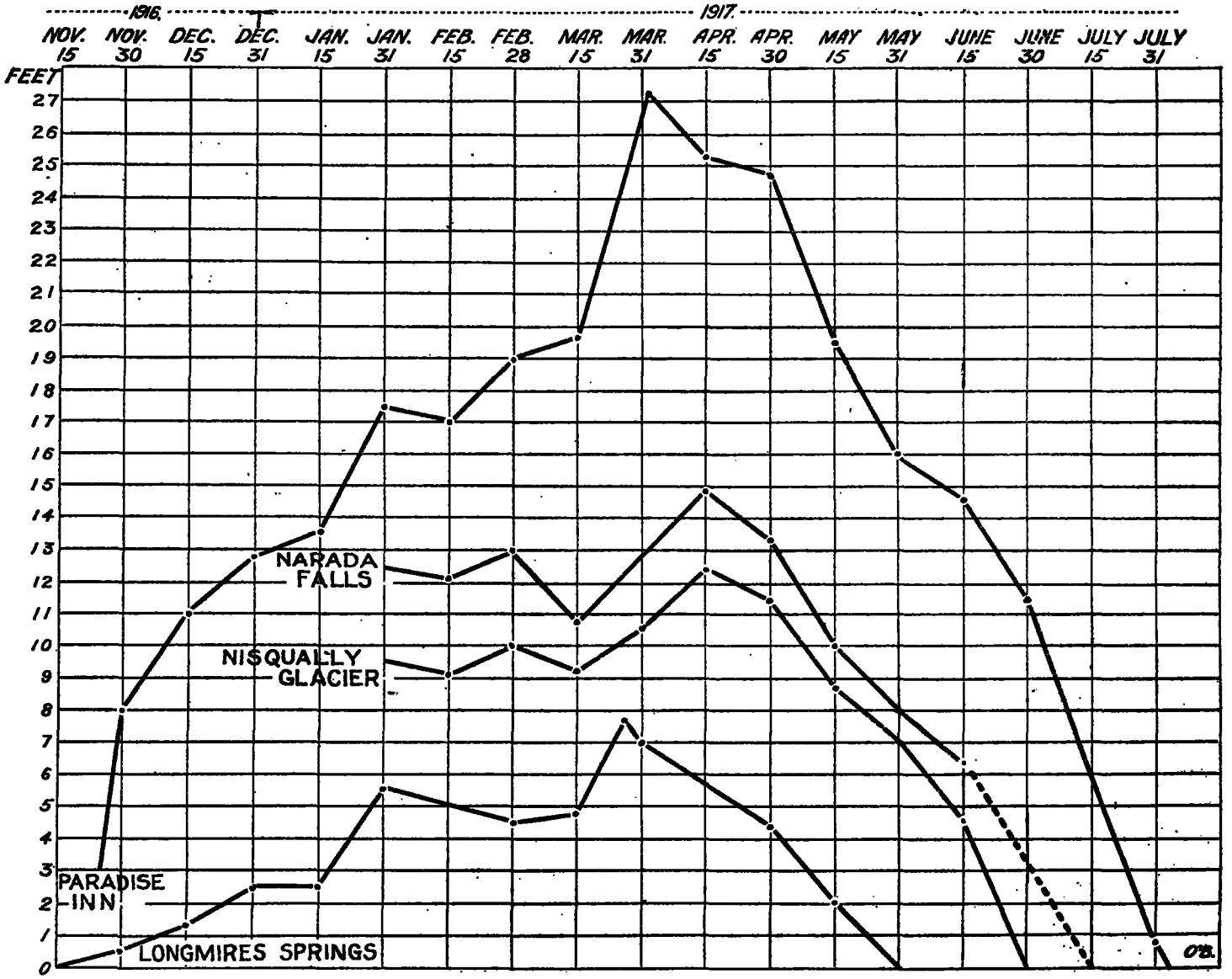

FIG. 1.—Depths of snow on Mount Rainier, Wash., 1916–17, at four elevations.

would be reasonable to expect the maximum precipitation approximately on the southwest slope. But the Paradise Inn station is located 1 mile east of the meridian passing through the summit, the distance to which is 4½ miles. In this respect it does not conform to the theoretical location for maximum precipitation. Indian Henry's Hunting Ground is located on the southwest side of the mountain, the elevation of the camp being 200 feet lower than Paradise Inn. It is generally understood among mountaineers that snow disappears earlier at Paradise Inn than at Indian Henry's, and in Summerland, at about the same elevation on the east slope, it disappears even earlier than in Paradise Valley. In the latter part of July, 1917, when there was considerable bare ground in Paradise Valley, Indian Henry's Hunting Grounds were still entirely covered with snow. There was less snow at this time in Summerland than in Paradise Valley. These facts at least harmonize with the principle of maximum precipitation on the windward slope and minimum on the leeward.

What the differences in the amount and intensity of sunshine may be at these three places is not known. The suns rays at midday are most effective on a south slope, but this alone is insufficient to account for all the phenomena; it does not explain the earlier disappearance of snow in Summerland on the east slope. Furthermore there is more sunshine recorded at Weather Bureau stations in this State in the afternoon than in the forenoon. A preponderance of sunshine in the afternoon would favor melting on the southwest slope; but, as has been stated, the snow in Indian Henry's is slowest to melt. What influence winds may have in this respect is unknown. From the evidence at hand, it appears that snowfall is greater on the southwesterly slope of the mountain than at Paradise Inn.

So far as known no observations have been made that would indicate whether there is a further increase in the amount of snowfall above the 5,500 foot level. In California snowfall records have been obtained as high as 7,000 and 8,000 feet, and they show an increase in the amount of snowfall over that at stations approximating the 5,500 foot level.[3] Yet one would hardly expect the maximum precipitation and snowfall in Washington to occur at the same height as in California, owing to the differences in latitude and the resultant climatic conditions. Records for other mountain regions can not be

[3] See Palmer, Ibid., p. 217.

considered conclusive evidence, though tending to corroborate a theory of greater snowfall above the 5,500 foot level, for it is not probable that the exact climatic, geographic, and topographic conditions can be duplicated anywhere closely enough to make conclusions by analogy justifiable. The problem is too local.

At the elevation of Paradise Inn snow usually disappears during the summer. Above this elevation are the great permanent snowfields, each covering several square miles, that feed a score of glaciers with ice as they creep down the valleys in summer, and contribute to the torrents of water that issue from beneath the glaciers during the warmth of the day. Mr. F. E. Matthes in his report for the United States Geological Survey on the "Glaciers of Mount Rainier" indicates that these névés are conspicuous between 8,000 and 10,000 feet elevation, while above that level the snow layer is perceptibly less, the air being too cold to carry enough moisture to cause the great precipitation received lower down.

With ascent above Paradise, the lowering temperature favors snowfall at times when rain occurs at the inn. Autumn and spring rains at Paradise are apt to be snow in the region of the snow fields. Even in winter southerly winds caused by a pronounced low pressure area carry warm rains up the slope as high as or higher than the inn. There seems to be little reason to doubt that the maximum annual snowfall will be found to occur higher up the slope than the 5,500-foot level.

Since the record at Paradise Inn covers only a part of one season, it is impossible to establish the comparative relation of the snowfall here to that at other points on the mountains of the Pacific slope. Furthermore, there is a scarcity of records on the extensive system of mountains reaching from Arctic regions southward beyond the latitude of prevailing westerly winds. Some reference to the possibilities seems desirable, however.

In the State of Washington it would seem that for the Cascades, Mount Rainier should show the greatest snowfall. The Olympics, which occupy nearly all the region between Puget Sound and the Pacific Ocean, show a greater average precipitation to their southwest than obtains for any station near the Cascades. The 12-year average for Clearwater, elevation 135 feet, and located a few miles from the seacoast, is 128 inches. A 9-year record at Quiniault, about 25 miles inland at an elevation of 300 feet, but where the country is mountainous, shows an average of 135 inches. These stations have considerably greater precipitation than has thus far been obtained at any station in the Cascades at any elevation. At Longmires Springs, on the south slope of Mount Rainier, elevation 2,761, a 5-year record yields an average of 78 inches; Yale's 10-year average at 375 feet elevation, farther south, yields 94 inches; at Snoqualmie Pass, elevation 3,000 feet, a 3-year record averages 87 inches; the 9-year record at Goat Lake at 2,900 feet elevation averages 94 inches; Cedar Lake's 14-year record at 1,546 feet averages 107 inches. No measurements have been made at equal elevations in the Olympics, but it is evident that at corresponding elevations precipitation is considerably greater than in the Cascades.

The factor of temperature must modify somewhat the proportion of precipitation that occurs as snow. In comparing mean temperatures at stations on or near the coast with those at approximately similar elevations near the Cascades the mean temperature for the most of the three winter months for the more inland stations is the colder, but in all other months of the year the monthly mean temperatures for stations on the west slope of the Cascades are the higher. During the months of greatest precipitation, November and December, the mean temperatures are very similar in both regions. It is true that extremes of temperature are greater for the Cascade stations; however, in view of the foregoing, one is not safe in minimizing the snowfall on the Olympics as compared with the Cascades, based upon the consideration of temperature, especially in view of the fact that Mount Olympus exceeds 8,000 feet in elevation. But very few official readings of snowfall depths have been made for the Olympics. These are for moderate elevations only, and while affording no basis for comparisons, they indicate a very heavy snowfall. Judgment may well be reserved as to which range has the greater snowfall. The obtaining of daily readings of snowfall in the rugged Olympics is still of the future and probably not of the near future.

As one proceeds northward from Washington on the Pacific slope, the period without precipitation in summer soon practically vanishes. There is no so-called dry season in southeastern Alaska and it appears that the quest for a greater snowfall than in Washington should be pursued there rather than to the south, where the season of snowfall is shorter. One can not hope to point out the region of greatest snowfall in a territory so vast as Alaska with records so few and at low elevations only. Precipitation records in the southeastern portion of the Territory show a 12-year average of 151 inches at Loring, and a five-year average of 165 inches at Ketchikan. A parallel record covering only 20 months shows that the precipitation at Jumbo Mine, elevation 1,500 feet, exceeds that of Ketchikan by 19 per cent, which would make the average for Jumbo Mine approximate 190 inches. These stations show a heavier precipitation than has been measured elsewhere on the Pacific slope, and it seems probable that with ascent of the mountains, which in some cases rise almost out of the ocean, and lie close to the paths of storms from the North Pacific, a greater snowfall will be found than for any other region of the continent.

With the further development of the Mount Rainier National Park, it will become possible gradually to extend the survey of snowfall on the mountain, and an unusual opportunity will be afforded for the study of variations in precipitation with elevation and exposure.

ON SEVERE WINTERS.[1]

By G. HELLMANN.

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A "character number" to express the degree of severity of any winter is obtained in the following way: The mean temperature in degrees centigrade for each day of the months November, December, and January is taken; of these the negative values are selected and added together; the result, viz, the sum of the negative daily means, is the character number. Of the last 150 winters in Berlin, 24 are classified as "very severe." The most severe was the winter of 1829–30, and that of 1788–89 was almost as severe. The winter of 1916–17 comes out only as a moderately severe one. Since the middle of the nineteenth century the number of very severe winters has been much reduced; in the period 1788 to 1845 that number was great, namely, 17. A very severe Berlin winter is associated with the presence of a prolonged snow covering, and a westerly position of the continental high-pressure system.—*R. C[orless.]*

[1] Preuss. Akad. Wiss., Berlin, 1917, 52: 738-759.